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RESEARCH

Biodiversity assessment of urban green spaces for multifunctional green space planning in high-rise residential housing areas

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Abstract

We assessed the biodiversity in urban green spaces in two study areas in Sweden, one in Malmö (Lorensborg and Bellevuegården) and one in Södertälje (Ronna). Both areas are characterised by high-rise residential housing built in the 1950s–1970s. These types of city districts have been investigated less often regarding their biodiversity values. Here, we have developed a method for biodiversity assessment of urban green spaces that can be performed at city district scale in particular in districts with public and residential green spaces. To assess biodiversity, we chose three measures: (1) number of habitats, (2) tree and shrub species (taxa) and (3) indicators such as the estimated abundance of dead wood, floral herbal resources and management intensity. Most green space types prevalent in both study areas were included, such as parks, residential green areas and street green (but not private gardens). Twenty-seven different habitat types were recorded, with lawns, hedges and shrubs being the most common. In total, 145 tree and bush taxa were identified; the proportion of non-native taxa was 73% in Malmö and 62% in Södertälje. In both study areas, we observed a high management intensity in many green spaces, which resulted in a diminished potential as wildlife habitats. Planning programmes were ongoing in both study areas. In Malmö, there are densification projects, which underline the risk of losing green infrastructure due to exploitation in these types of city districts. Among biodiversity assessment methods, our methodology is of medium intensity and combines direct measures with indicators for biodiversity.

Keywords Biodiversity indicators · Biodiversity mapping · Green infrastructure · Habitat · Million Housing Programme · Sweden

Introduction

The need for multifunctional urban green space is more crucial than ever in times of urbanisation, climate change and biodiversity loss (Kabisch 2015; Pauleit et al. 2019). This is even more the case in the context of urban densification, which often leads to a decrease in green areas (Lin et al. 2015; Colding et al. 2020). Urban green space needs to fulfil a large number of important functions such as recreation, water and climate regulation, and providing habitats for species, while human population density is increasing and green space is declining (Kabisch 2015). To be able to provide green space that delivers this array of ecosystem services, green space has to be designed, planned and managed accordingly (Madureira and Andresen 2014; Shi and Woolley 2014). To promote the multifunctionality of green space, a necessary precondition is to identify existing and missing functions, as well as potential synergies and conflicts between these (e.g., biodiversity, recreation, aesthetics). As a first step to achieve multifunctionality of urban green space, systematic assessments of existing functions are needed (Daniels et al. 2018; Hansen et al. 2019).

Regarding biodiversity assessment of urban green space, a number of different methods have been presented, both for assessing biodiversity only (e.g. Hermy and Cornelis 2000; Tzoulas and James 2010) and for combining biodiversity with other assessments in an interdisciplinary context (e.g. Qiu et al. 2013; Hand et al. 2016; Daniels et al. 2018). Depending on the aims, these methods have been developed

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for different scales (from park size up to city size) and they have thus been either more selective (including only certain green space types) or more comprehensive (including most urban green space types existing in the study area). Hermy and Cornelis (2000) introduced a comprehensive method for the biodiversity assessment of urban parks. About 70 different habitat units were identified and mapped, forming the basis for measuring habitat diversity. Additionally, vascular plant species, breeding birds, amphibians and butterflies were recorded. Hand et al. (2016) used biodiversity indicators such as compositional richness, structural complexity and wildness (which includes aspects of management and naturalness). The compositional richness included plants, birds and invertebrates. Qiu et al. (2013) assessed the biodiversity in an urban park in Sweden by surveys of vascular plants, combined with the percentage of non-native species, intensity of management, and complexity of habitat structure.

These methods can give very good estimates of biodiversity. However, they are labour-intensive and time-consuming. Therefore, simpler assessment methods have been suggested. These are characterised by less comprehensive habitat lists and focusing on certain biodiversity indicators, for example tree cover. Species sampling is often confined to plant species and at a less detailed level. Tzoulas and James (2010) developed a rapid assessment method for urban biodiversity, based on plant recordings at genus level and indicators such as vegetation structure and percentage of built-up area.

Beyond these studies focusing on urban biodiversity assessment, there is a large number of studies that investigate urban green space from a multidimensional perspective and where ecological values including biodiversity are only one aspect studied (Daniels et al. 2018; Gonçalves et al. 2021; Kraemer and Kabisch 2021). In these studies, there are often no species recordings, but assessments are based on biodiversity proxies or ecological indicators. For example, Daniels et al. (2018) used indicators for ecological integrity, habitat potential for plants and animals, and pollination. Kraemer and Kabisch (2021) based indicators for assessing the natural elements in urban green space on different aspects of vegetation structure (vegetation cover, vegetation layers) and characteristics of water bodies (water cover, stream density). In studies with a multidimensional perspective on green space, biodiversity is often assessed at habitat level or with land-cover types and less often through species recordings. There are, however, also examples of studies that use existing species databases as an indicator of biodiversity (e.g. Cohen et al. 2012).

In this study, we aim to develop and apply a method for biodiversity assessment of urban green spaces that can be used in the context of socio-ecological studies and in particular to inform planning at city district level. Here we focus on high-rise residential housing areas with lower socio-economic status as a part of a larger research project (VIVA-PLAN) that concentrates on these type of city areas. The biodiversity of high-rise residential housing areas with lower socio-economic status has been studied less often at the detailed scale of the city district, although it has been acknowledged that they may have important biodiversity values (Beer et al. 2003). While biodiversity and socio-economic status are often positively related within cities (Kuras et al. 2020), there are examples where higher biodiversity can occur in more deprived urban areas (Cohen et al. 2012; Kuras et al. 2020). Within the VIVA-PLAN project, also social values were spatially mapped with the help of PPGIS (Participatory Geographic Information System) (see Raymond et al. 2021; Stålhammar and Raymond 2024).

The scale of the study is the city district, since local development plans are ongoing at this scale. The two study areas chosen are dominated by high-rise buildings and include a large proportion of semi-public green space and green areas belonging to residential areas. Another aim of the study was to gain knowledge on urban biodiversity in this type of city district, since urban biodiversity has been studied here less often. This is especially true in a Scandinavian context. We aim to identify similarities and differences between the two study areas, which are situated in two different geographic regions within Sweden. Finally, our goal is to identify important existing and missing aspects regarding biodiversity to inform the ongoing planning process in the two areas, with the overall aim of supporting and improving biodiversity as one aspect of multifunctional green space planning in these areas.

We address the following research questions:

- How can biodiversity in urban green spaces be assessed at city district scale in the context of socio-ecological studies and/or city district planning?
- How can the method be applied in a high-rise housing area?
- What are the similarities and differences regarding biodiversity in the two chosen study areas in Sweden?
- How can biodiversity be improved in the study areas?

Methods

Study areas

Between 1965 and 1975, high-rise residential housing areas were built in Swedish cities as part of the so-called Million Housing Programme (Borgegård, 2004; Mack 2021). This programme aimed to modernise Swedish housing by building one million homes, providing affordable housing with adequate living standards for a growing number of inhabitants who needed homes. These areas were often planned with a large amount of green space and included car-free areas (Mack 2021). Today, many inhabitants in Million Housing Programme areas have below average income, are more often unemployed and more often have a migrant background compared to the residents of other urban districts.

Lorensborg and Bellevuegården in Malmö and Ronna in Södertälje were chosen as study areas since they represent typical Million Housing Programme areas (Fig. 1). They are similar in terms of building and green space structure, socio-economic status, and ongoing planning challenges. With 350 000 inhabitants, Malmö is Sweden's third largest city. Södertälje (100 000 inhabitants) is part of the greater Stockholm region. Both Lorensborg/Bellevuegården and Ronna are dominated by multi-storey housing with rental apartments. In both areas, plan programmes are in progress. These relate to a densification project in Lorensborg and Bellevuegården, and the redevelopment of green spaces and possible densification in a longer time perspective in Ronna.

Lorensborg and Bellevuegården, Malmö

Lorensborg and Bellevuegården are two adjacent city districts situated in the western part of Malmö, next to the inner city. Lorensborg has an area of about 0.37 km^2 and

Fig. 1 Location of the two study areas in Sweden: Malmö (Lorensborg and Bellevuegården) and Södertälje (Ronna) (based on Wikipedia)

Bellevuegården has an area of 0.5 km^2. Lorensborg was built at the end of the 1950s, while Bellevuegården emerged in the 1970s (Skåne County Administrative Board and Malmö Kulturmiljö 2002, 2004). Thus, Lorensborg was built just before the start of the Million Housing Programme era and Bellevuegården at the end of it. However, the urban form is similar to Million Housing Programme areas. Both areas are dominated by multi-storey housing of up to 16 floors. Most of these are rental apartments, but some of the apartment blocks have tenant-owned apartments. Today, about 9 500 inhabitants live in the two districts (City of Malmö 2021a). The two districts are characterised by lower than average income and below average employment rates (City of Malmö and SCB 2021). The percentage of inhabitants with migrant background varies between 58% (Lorensborg) and 64% (Bellevuegården).

Both districts currently have a high proportion of green space, which consists of parks, residential green spaces (see Fig. 2a and b) and other green infrastructure (tree avenues and other street green typologies). Ownership of these green spaces is both public and private (mainly housing companies), and ownership boundaries are often not marked or visible. In the two districts, a large densification project is planned (City of Malmö 2021a) and began in 2021. The aim is to build 1200 housing units, mostly in a parking area, some residential green spaces and street green (tree avenues). The area covered by the plan programme is about 62 ha. The study area considered in this study is slightly larger, since adjacent parks were included, and has a size of about 73 ha.

Ronna, Södertälje

Ronna is a district in Södertälje with about 7300 inhabitants and an area of 1.6 km^2, located 2.5 km from central Södertälje (Södertälje Municipality 2022a). Ronna was built in the 1960 s as a part of the Million Housing Programme (Mack 2017). Ronna has a combination of multi-storey housing with

Fig. 2 Green spaces in the study areas: **a**) Residential green, Lorensborg, Malmö, Sweden (Photo C. Haaland); **b**), Ärtholms park, Bellevuegården, Malmö, Sweden (Photo: C. Haaland); **c**) Residential green, Ronna, Södertälje, Sweden, (Photo: K. Lehtilä); **d**) Closeness of residential area to forest, Ronna, Södertälje, Sweden (Photo: K. Lehtilä)

rental apartments in the northern part of the district and tenant-owned terraced houses and detached houses in the western and southern parts. Of the population, 91% has a migrant background (SCB, 2021). More than half of the district can be classified as green space, consisting in large part of coniferous-deciduous mixed forest owned by the municipality, as well as neighbourhood and street green (Fig. 2c and d), owned by the municipality and the housing companies. In the southern area of individual houses, most of the urban green consists of gardens and yards on private lots. Densification plans are included in the strategic planning for Södertälje, with Ronna being mentioned as one district to be densified. Detailed plans have not been drawn up for these initiatives.

Methods for green space inventorying

The chosen methodology for the inventory of green spaces for the evaluation of biodiversity at a city district scale is a balance between the ambition to differentiate green spaces regarding their biodiversity and what is feasible regarding available resources for the survey at this scale. Direct measures of biodiversity (number of woody species, number of habitats) were combined with indicators for biodiversity (large trees, dead wood, floral resources, management intensity), which are all well established (e.g. Klaus 2013; Qiu et al. 2013; Hülsmann et al. 2015; Hand et al. 2016; Müller et al. 2018; Korhonen et al. 2020).

Biodiversity assessments were carried out at the level of green space recording units, which comprised almost all green spaces in the area. Excluded were small front- or backyards in direct connection to buildings (often with private character). School and kindergarten yards were also excluded from the study. Similarly, yards and gardens on individual private housing lots in Ronna were also excluded. The boundaries of the recording units were often based on visual boundaries. Visual boundaries mean, for example, that a green area in front of an apartment block was regarded as one recording unit. This could contain different habitats such as a lawn, a tree line, a hedge and a flower bed, and be delimited by roads, building edges, etc. This approach was chosen since the results of the ecological data were also applied as a map overlay together with results gained from the PPGIS (Participatory Geographic Information System) survey carried out in the study areas (Raymond et al. 2021; Stålhammar and Raymond 2024). Thus, the scale of the recording units for the biodiversity assessment was adapted to the scale of answers from the PPGIS survey. This meant that the habitats themselves would have been a too fine-grained scale, since for example inhabitants distinguished a backyard as a unit, which could contain many different habitats. Parks were usually treated as one recording unit. Recording units were most often dominated by vegetated areas, but some hard surface areas were also included, for example parking places or cycling and walking paths close to and surrounded by green spaces. Larger unvegetated areas were not included in the inventory. The methodology was also seen as suitable in a planning context, where mapping of single habitats for example within parks or residential areas are assumed to be too labour-intensive and time consuming.

The biodiversity assessment in each unit was based on three different methods:

- Recording of habitat types.
- Recording of tree and bush taxa (both native and non-native ones).
- Recording of biodiversity indicators.

In addition, recording units were classified according to the general green space typologies developed by Cvejić et al. (2015). Recording units could be classified by one or a maximum of two typologies (see Appendix Table 3 for applied typologies). This classification was done to describe the green spaces prevalent in the two study areas in more detail; however, the classification was not used for the biodiversity assessment. The green space typologies emphasise structural characteristics of urban green (Appendix Table 3), whereas habitat types (see below and Appendix Table 4) give direct information about the habitat diversity of recording units. To give an example, many recording units were classified to the green space typology of neighbourhood green space, while the same recording units could have many different habitat types such as lawn, tree row, flower bed, shrub plantation and so on.

The recording units were defined in the study areas at the same time as the first occasion of recording habitats, trees and shrubs, and biodiversity indicators (see below). Recording units were mapped in the geographic information system (GIS) ArcGIS (ArcGIS Pro 3.0.1, ESRI 2022; ArcGIS Desktop 10.6, ESRI 2018). The area of the recording units was calculated using the GIS.

Recording habitat types

An inventory of habitat types was produced in each recording unit. The habitat types recorded were based on the list developed by Hermy and Cornelis (2000), modified for the habitat composition in our study areas where, after a pilot round in both study areas prior to the recordings, some additional habitat types were included in the list. The list of habitats applied can be seen in the Appendix (see Appendix Table 4). For each recording unit, the number and identity of habitat types was noted, but habitat boundaries within the units were not mapped.

Recording trees and shrubs

An attempt was made in every recording unit to record all tree and bush species, both native and non-native. This was done by walking through the green space unit, e.g., along hedges, all bush plantings, etc. Recordings were carried out in all units on two occasions in both study areas in summer/autumn 2020 (July–September). A complementary survey was carried out in Lorensborg and Bellevuegården in May 2021.

Non-native species could be hard to identify at species level. In these cases, trees and bushes were only identified at genus level. The analysis was thus done at a level of taxa combining both genus and species level. Tree and bush species were divided into native or non-native taxa based on Rydberg and Wanntorp (2001) and Mossberg and Stenberg (2010), and in Malmö with additional information from Weimarck and Weimarck (1985). When a taxon could not be identified at species level, it was nevertheless identified within genus down to a level so that it could be distinguished as native or non-native.

Recording of biodiversity indicators

The following indicators for biodiversity were recorded:

- abundance of old/large trees (fully grown).
- lying dead wood (fallen or cut logs).
- standing dead wood (standing dead trees).
- areas with high grass vegetation (above 30 cm).
- floral herbal resources (potentially pollinator friendly).
- management intensity.

These factors are recognised as supporting urban biodiversity (e.g. Klaus 2013; Hülsmann et al. 2015; Müller et al. 2018; Korhonen et al. 2020).

Table 1 Components of biodiversity assessment method

Components	Surveys	Comment
Habitat heterogeneity	Number of habitats	Classification according to Hermy and Cornelis (2000)
Species richness	Number of tree and shrub taxa	Divided by log area
	Number of native tree and shrub taxa	Divided by log area
Biodiversity indicators	Abundance of old/large trees	
	Dead wood, lying	
	Dead wood, standing	
	High grass vegetation	
	Floral herbal resources	
	Management intensity	

For all indicators other than management intensity, the abundance was estimated in four classes from 0 to 3, where 0 means absent, 1 means few, 2 means abundant and 3 means very abundant. For management, the intensity of management was estimated between 1 and 3, where 1 is low management intensity, 2 is medium and 3 is high (Qiu et al. 2013). Indicators for high management intensity include very frequent lawn cutting, which results in short grass sward with no or with few floral resources, frequent removal of weeds and trimming of hedges.

Biodiversity analysis

For the analysis, the following variables were calculated for each unit of recording on the basis of the field inventories (see also Table 1):

- Number and type of habitats.
- Number of tree and bush taxa divided by $\log_{10}$ area (distinguished between native and non-native).
- Biodiversity indicators.

Statistical analysis

Statistica (TIBCO 2021) and R (R Core Team 2022) were used for the descriptive statistics and regression analysis. Canonical correspondence analysis (CCA) was carried out with R package vegan (Oksanen et al. 2022). CCA was used for the ordination of habitat types to a pattern that is maximally associated with the biodiversity indicators. The indicators included in the CCA were floral herbal resources, management intensity, and the abundance of old trees. In addition, the number of taxa/log(area) was included as a biodiversity indicator. Abundance of dead wood was excluded because it had little variation (most units did not have dead wood), and areas with high vegetation was omitted because pilot analyses showed that this was very closely associated with meadow habitat type, i.e., they had almost exactly the same information. The significance of CCA axes and biodiversity indicators were analysed with a permutation test (1000 permutations, type III test).

Results

Recording units

Ninety-two recording units were distinguished in Lorensborg and Bellevuegården, and 211 in Ronna. The average size was 0.53 ha (min. 0.02 ha, max. 6.0 ha) in Lorensborg and Bellevuegården, and 0.35 ha (min. 0.01 ha, max. 11.5 ha) in Ronna. The total area of the recording units was

48.5 ha in Lorensborg and Bellevuegården and 73.2 ha in Ronna.

General green space typologies

The main green space typologies found in Lorensborg and Bellevuegården (Malmö) were neighbourhood green (32 recording units, 38% of the investigated green spaces) and street green in form of tree avenues and street trees and hedges (28 recording units, 20% of the area) (see Appendix Table 3). Seven recording units were classified as parks (32% of the area) and two as pocket parks (1% of the area). There were also some institutional green spaces ($n=4$, 1% of the area). Eighteen recording units were classified as belonging to two typologies; these were neighbourhood green, pocket parks and institutional green spaces in combination with woody street green (totalling 9% of the area).

The most common green space typology in Ronna was neighbourhood green (126 recording units, 60% of the area). Green verges and forest were also common (26 and 35 units; 12% and 17% of the area, respectively). Less common typologies included grassland (13 units, 6% of the area), tree avenues (five units, 2% of the area), pocket parks (four units, 2% of the area) and shrubland (two units, 1% of the area).

Habitat types

A total of 21 habitat types were identified in Lorensborg and Bellevuegården, and 16 in Ronna (see Appendix Table 4). The mean number of habitat types was 4.5 per recording unit in Lorensborg and Bellevuegården (min. 1, max. 9, SD 1.8). In Ronna, there were on average 2.6 habitat types per recording unit (min. 1, max. 6, SD 1.2).

The most common habitat types recorded in Lorensborg and Bellevuegården were hedges, lawns, shrubs, and lawns with trees (Fig. 3). In Ronna, lawns and lawns with trees were the most common habitat types, together with grassland and shrubs. An apparent difference between the two study areas is that Ronna had a far higher amount of forest habitats. The landscape of Lorensborg and Bellevuegården is flat with sedimentary soils, while the Ronna landscape has hills with tops and slopes without soil cover. Thus, there were no outcrops in the study areas in Malmö, but these were regular features in Ronna.

Figure 4 shows maps of the number of habitat types in recording units in the two study areas. The number of habitats is partly dependent on the size of the recording unit (Lorensborg and Bellevuegården: number of habitat types $=2.301$ log(area in m^2) – 3.458, $R^2=0.358$; Ronna: number of habitat types $=1.100$ log(area in m^2) – 0.974; $R^2=0.170$; $P<0.001$; linear regression). The type of greenspace also influences habitat numbers. In Lorensborg and Bellevuegården, the mean number of habitats in recording units classified as parks is similar to neighbourhood green, despite the average size of neighbourhood green being 25% of the size of parks. This can also be seen in Fig. 4a, where larger parks (in the east of the study area) may have fewer habitats than some of the residential areas (which are smaller in size). Ronna did not have any urban parks. The centrally located large forested unit had the largest number of habitats (six habitat types), together with some smaller units with neighbourhood green (Fig. 4b). Marginally located forested units had only intermediate numbers of habitats (three or four habitat types). The habitat mapping made the lack of water habitats in both study areas particularly apparent.

Tree and shrub taxa

In Lorensborg and Bellevuegården, 117 tree and shrub taxa were identified. About one quarter (27%) of the taxa were native, and three quarters (73%) were non-native (see

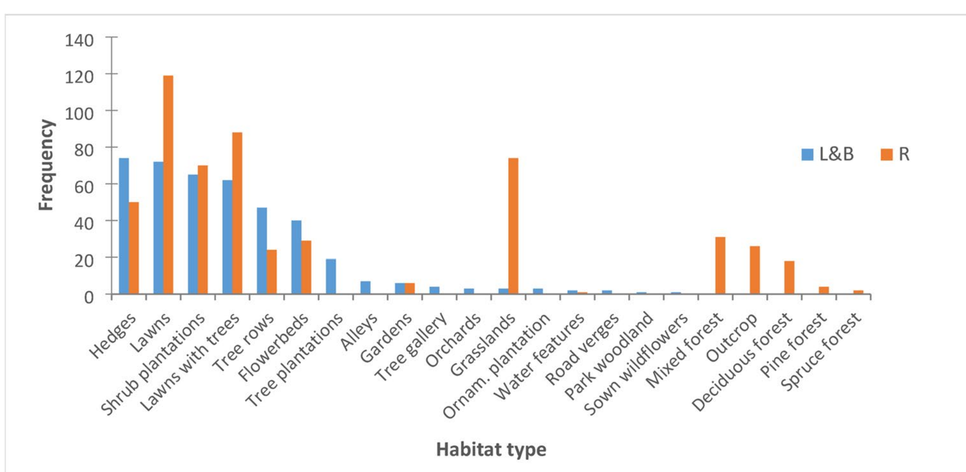

Fig. 3 Frequency of habitats in recording units in the two study areas L & B (Lorensborg & Bellevuegården, Malmö) and R (Ronna, Södertälje). For the category flowerbeds habitat types rose garden (1.10.3), flower bed (1.11.3), flower bed with shrubs (1.11.2) were combined (numbers refer to Table 4)

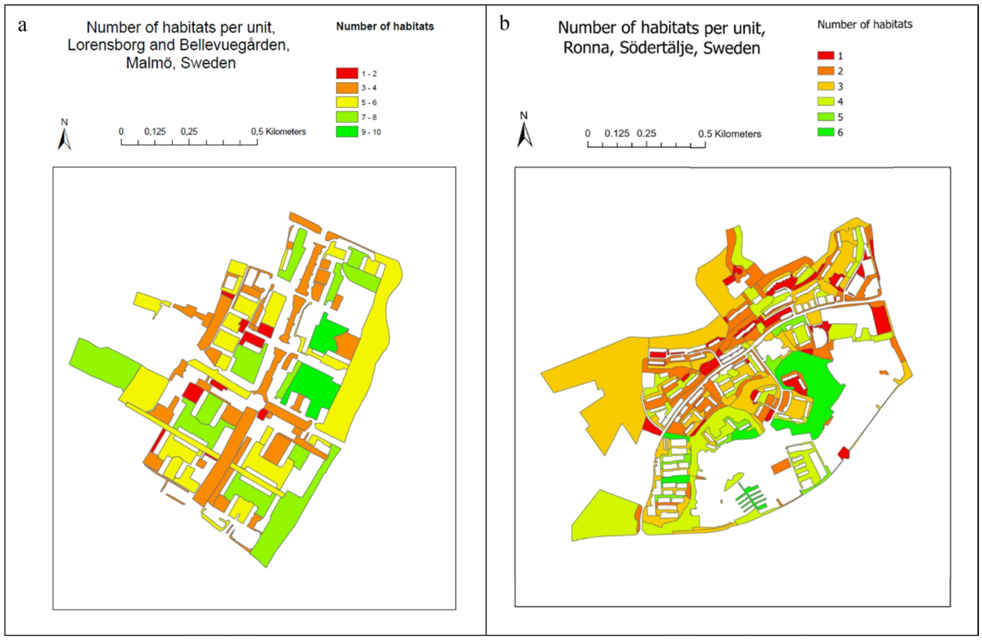

Fig. 4 Maps of the two study areas presenting the number of habitat types per recording unit (**a**) Lorensborg & Bellevuegården (**b**) Ronna. (Colours used for habitat numbers do not match between study areas, since the grading focuses on in-between study area differences)

Appendix Table 5). Four genera were counted in more than one category (*Crataegus* spp., *Cotoneaster* spp. and *Salix* spp. included as both native and non-native species; *Sorbus* spp. as both tree and shrub species). In Ronna, 90 taxa were identified of which 37% were native and 63% were non-native (see Appendix Table 5). Altogether, 145 taxa were distinguished. Both in Lorensborg and Bellevuegården and in Ronna, more shrub species were recorded than tree species. While the numbers of native tree and shrub species were similar in both study areas, Lorensborg and Bellevuegården had considerably higher numbers of non-native species (shrubs and trees).

In Lorensborg and Bellevuegården, broad-leaved taxa dominated by far. Tree species with the highest frequencies were elm (*Ulmus glabra*, often young trees, not planted), Norway maple (*Acer platanoides*), field maple (*Acer campestre*) and wild cherry (*Prunus avium*). The most frequent native shrub species were hawthorn (*Crataegus monogyna* and *C. laevigata*) and elder (*Sambucus nigra*). Sycamore (*Acer pseudoplatanus*) and apple trees (*Malus* spp.) were frequent non-native trees, while roses (*Rosa* spp.), *Cotoneaster* spp. and *Spirea* spp. were frequent non-native shrubs, which were found in more than half of all recording units.

Broad-leaved tree species (Norway maple, *Acer platanoides*; silver birch, *Betula pendula* and rowan, *Sorbus aucuparia*) were also most frequent in Ronna. Scots pine (*Pinus sylvestris*) occurred in a third and Norway spruce (*Picea abies*) in a fifth of the recording units in Ronna. As in Lorensborg and Bellevuegården, hawthorn and elder were among the most common native shrub species, with hazel (*Corylus avellana*) and raspberry (*Rubus idaea*) also being recorded in Ronna. Non-native tree species were only recorded in Ronna at low frequencies, with apple (*Malus domestica*) being the most common species (frequency 14%). As in Bellevuegården, roses (*Rosa* spp.) were by far the most common non-native shrub, occurring in almost half of the units. *Cotoneaster* spp., *Syringa* spp. and *Spirea* spp. were among the most frequently recorded non-native shrubs, but all occurring at frequencies below 20%.

Tree and shrub taxa in recording units

On average, 16.0 different shrub and tree taxa were recorded per unit in Lorensborg and Bellevuegården (min. 1, max. 49, SD 11.1; see also Table 2). The mean numbers for non-native shrub taxa are the highest (mean 8.3, min. 0, max. 27, SD 6.5), followed by native tree taxa (mean 3.2, min. 0, max. 12, SD 2.3). On average, there were 2.5 non-native tree taxa (min. 0, max. 10, SD 2.1) and 2.0 native shrub taxa (min. 0, max. 7, SD 1.9) per recording unit. In Ronna, the mean number of taxa recorded was half of that in Lorensborg and Bellevuegården (mean 7.2, min. 0, max. 30, SD 4.9). This was mainly due to a lower number of non-native taxa (non-native tree taxa: mean 0.4, min. 0, max. 3, SD 0.7; non-native shrub taxa mean 2.0, min. 0, max. 15, SD 2.3). The mean number of native tree taxa was slightly higher in Ronna than in Lorensborg and Bellevuegården (mean 3.8, min. 0, max. 14, SD 3.0). However, native shrubs were more common in Lorensborg and

Table 2 Total number and percentage of bush and tree taxa, and mean numbers per recording unit in the two study areas Lorensborg and Bellevuegården (Malmö) and Ronna (Södertälje) divided into native and non-native taxa

	Lorensborg & Bellevuegården (Malmö)			Ronna (Södertälje)		
	Total number	% of total number of taxa (n=117)	Mean number of taxa per recording unit (n = 92)	Total number	% of total number of taxa (n=90)	Mean number of taxa per recording unit (n=211)
Native tree taxa	19	16%	3.2	18	20%	3.8
Native shrub taxa	13	11%	2.0	15	17%	0.9
Non-native tree taxa	34	29%	2.5	17	19%	0.4
Non-native shrub taxa	51	44%	8.3	40	44%	2.0
Sum	117	100%	16.0	90	100%	7.2

Bellevuegården than in Ronna (mean 0.9, min. 0, max. 7, SD 1.3).

The number of taxa was positively correlated with the log area of the recording unit (Lorensborg and Bellevuegården: number of taxa = 14.64 log(area) – 34.75, R^2 = 0.369; in Ronna, the relationship was similar: number of taxa = 6.17 log(area) – 12.66, R^2 = 0.321; P < 0.001 in both tests; linear regression).

Figure 5 shows maps of the study areas presenting the number of tree and shrub taxa divided by log area per recording unit (for all tree and shrub taxa and for native tree and shrub taxa). In Lorensborg and Bellevuegården, it is mostly the residential areas that have the highest numbers of recorded taxa (taking differences in area into account), while street green often has a low number of tree and shrub taxa. Interestingly, lower numbers of taxa were often recorded in parks (e.g. Stadionparken, Ärtholmsparken, large units in the far east of the study area) than in residential areas, with the exception Bellevueparken (the unit furthest to the west). When considering only native taxa, this picture changes slightly. Bellevueparken is still the only park with a higher number of native taxa (divided by log area). However, there are fewer residential areas with a higher number of native taxa/log area. Street green generally had a low number of native taxa/log area.

In Ronna, the highest number of taxa (taking into account the unit area) was observed in forested units and two housing compounds in the southern part with terraced houses (Fig. 5c). Street green in the main streets and many green areas around high-rise buildings, often dominated by lawns, had a low number of woody taxa. The highest numbers of native taxa were found in forests and areas of wild vegetation (Fig. 5d). Street verges had a high number of native taxa when they consisted of wild vegetation instead of lawns and planting. Green spaces in residential areas had a low number of native taxa, except in one housing compound where the number of all woody taxa was also high.

Biodiversity indicators

The results from recording indicators for biodiversity show that old/large trees are relatively abundant in both study areas, while dead wood is scarce – especially standing dead wood (Figs. 6a-c). High grass vegetation and flowering herbal vegetation is rather less abundant in Lorensborg and Bellevuegården (Malmö), but occurs regularly in Ronna (Figs. 6d-e). Overall, the management intensity of many sites is estimated as high in Malmö, while Ronna had sites with both high and low management intensity (Fig. 6f).

Canonical correspondence analysis (CCA)

The first axis of CCA in Malmö orders the habitat types according to management intensity (Fig. 7a; variance explained by CCA axis 1 was 40.5% and by CCA axis 2 26.7%). Management intensity was not detrimental to species richness. Many habitats, like flower beds and flower gardens, increased the number of taxa. The CCA of Ronna shows that management intensity and the availability of pollinator resources were the main factors structuring different habitat types. The first axis of CCA has a close negative association with management intensity and a positive association with old trees. It orders the habitat types from managed to wild vegetation, with lawns, gardens, flower beds and hedges on the left side and forested units on the right side (Fig. 7b; variance explained by CCA axis 1 was 11.6% and by CCA axis 2 3.0%). The second CCA axis orders the habitat types primarily by the availability of pollinator resources. All biodiversity variables contributed significantly to the models of both study areas (permutation test


a
Number of all taxa/log area
Lorensborg and Bellevuegården,
Malmö, Sweden
All taxa/log area (m2)
0-2
2-4
4-6
6-8
8-10
10-14
N
0 0,125 0,25 0,5 Kilometers
b
Number of native taxa/log area
Lorensborg and Bellevuegården,
Malmö, Sweden
Native taxa/logarea (m2)
0
1
2
3
4
5
N
0 0,125 0,25 0,5 Kilometers
c
Number of all taxa/log area
Ronna, Södertälje, Sweden
All taxa / log area (m2)
0 - 1
1 - 2
2 - 3
3 - 4
4 - 9
N
0 0.125 0.25 0.5 Kilometers
d
Number of native taxa/log area
Ronna, Södertälje, Sweden
Native taxa / log area (m2)
0 - 1
1 - 2
2 - 3
3 - 4
4 - 5
N
0 0.125 0.25 0.5 Kilometers

Fig. 5 Maps of the two study areas presenting the number of taxa and native taxa per recording unit in relation to its log area; (**a**) Lorensborg & Bellevuegården all taxa, (**b**) Lorensborg & Bellevuegården native taxa, (**c**) Ronna all taxa, (**d**) Ronna native taxa. (Colours used for habitat numbers do not match between study areas, since the grading focuses on in-between study area differences)

$P<0.01$), and the first two CCA axes were highly significant ($P<0.001$).

Discussion

Woody species richness and biodiversity indicators in green spaces in the two Million Housing Programme areas

The results of this study show that the investigated Million Housing Programme areas can provide green spaces with a relatively high diversity of tree and shrub species. In the study area in Malmö, certain residential areas and one of the parks had a particularly high number of tree and shrub species. In Ronna, forests stood out with their diversity of woody species, together with certain residential areas. The abundance of old/large trees also made a positive contribution to the biodiversity in the study areas. At the same time, certain indicators for biodiversity such as dead wood and water were low in both study areas, and high and flower-rich grassland vegetation was rare – particularly in the study area in Malmö. Lawns were a dominant feature, especially in the larger parks and in the yards of housing compounds, which offer habitats for only a very limited number of species. While the problem of species-poor lawns in urban green spaces is widely acknowledged (Hedblom et al. 2017) and the concept of urban meadows (e.g. Norton et al. 2019) is increasingly applied, this has not resulted in any larger areas of higher grass vegetation including flowering herbs in the Malmö area. Due to a different geomorphology in the Ronna area, with outcrops and a lower management intensity, higher grass vegetation with flower resources is more abundant here. The importance of water for urban biodiversity is well known (e.g. Higgins et al. 2019), and the almost total absence of water features at this scale in both study areas is thus problematic from a biodiversity perspective. Biodiversity could be increased by reducing management intensity and establishing urban meadows and aquatic habitats. Dead wood is another scarce resource, even if it has been left in situ in several green spaces when lying on the ground. Standing dead trees are a safety issue and are therefore often taken down (see also Fröhlich and Ciach 2020). In Ronna, fallen trees could have been left as dead wood in the forest, but they are removed as part of forest management.

One of the major results of this study is that residential green spaces not only constitute a large proportion of the green space in the study areas but also contribute significantly to tree and shrub diversity. This is especially true for non-native species but also applies to native species. The fact that residential green space can make potentially a considerable contribution to urban biodiversity is well-known (Delahay et al. 2023). However, residential green space in form of private home gardens is by far more often studied than semi-public green space of multi-story houses (Delahay et al. 2023). Only recently the semi-public greenspace of multi-story houses has got attention (e.g. Zwierzchowska et al. 2021). Tree and shrub diversity is rarely investigated in public, semi-public and private green space in the same study area. Therefore, it is difficult to compare our results to other similar studies.

Similarities and differences between the two study areas

There are several distinct differences between the two study areas, which can be explained partly by different natural preconditions such as climate and geomorphology (Sjörs 1999), and partly by management (Södertälje Municipality 2022b; City of Malmö 2021b). The colder climate in Södertälje results in fewer – and to some extent different – species. Malmö is part of the southern deciduous zone in Sweden, while Södertälje is included in the southern coniferous zone. These differences in the natural vegetation zones are also visible in the investigated urban green spaces, with an overall dominance of deciduous tree species in the Malmö area and more coniferous species in the Södertälje area. Forest habitats are also more common in Ronna than in Lorensborg and Bellevuegården, since Malmö is situated in a deforested part of a plain, while the area surrounding Södertälje is partly forested. Despite these differences, all native tree taxa in Lorensborg and Bellevuegården were also recorded in Ronna, even though some of them were classified there as non-native. In addition, most native shrub species occur in both study areas. The differences between the study areas are greater when it comes to non-native species. Here, many species that are planted in the Malmö area were not present in Ronna, mostly because they could not grow in the colder more northern climate, but also due to choices in the design and management of green spaces.

Differences in geomorphology lead to two major differences. In geological terms, the Malmö area is dominated by till and there are almost no height differences in the area.

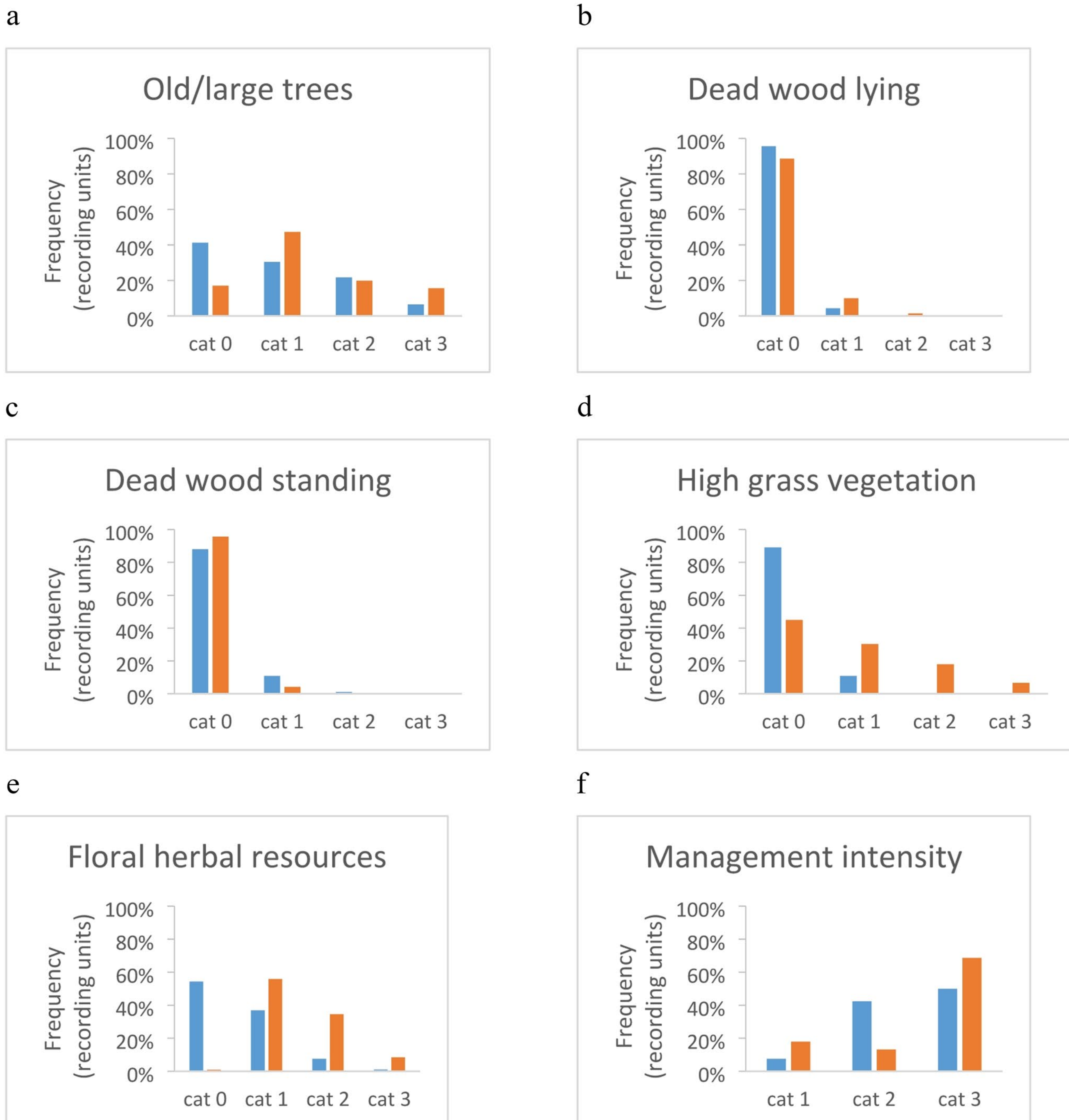

Fig. 6 Biodiversity indicators, frequency of different categories in the two study areas; blue: Lorensborg & Bellevuegården, Malmö and orange: Ronna, Södertälje; (**a**) old/large trees, (**b**) dead wood lying, (**c**) dead wood standing, (**d**) high grass vegetation, (**e**) floral resources, pollinator friendly, (**f**) management intensity. All categories besides management intensity: 0 = absent, 1 = few, 2 = abundant, 3 = very abundant; management intensity: 1 = low, 2 = medium, 3 = high intensity

Ronna's landscape is hilly, with outcrops, which are usually less intensively managed and allow more easily for natural or semi-natural vegetation including flower-rich vegetation. According to CCA, management intensity was important in structuring habitat diversity in both study areas. In Ronna, there are also more areas with low management intensity than in Lorensborg and Bellevuegården. Together this may explain the higher abundance of high grass vegetation and floral resources. In Ronna, the second CCA axis ordered the habitat types mainly by pollinator resources.

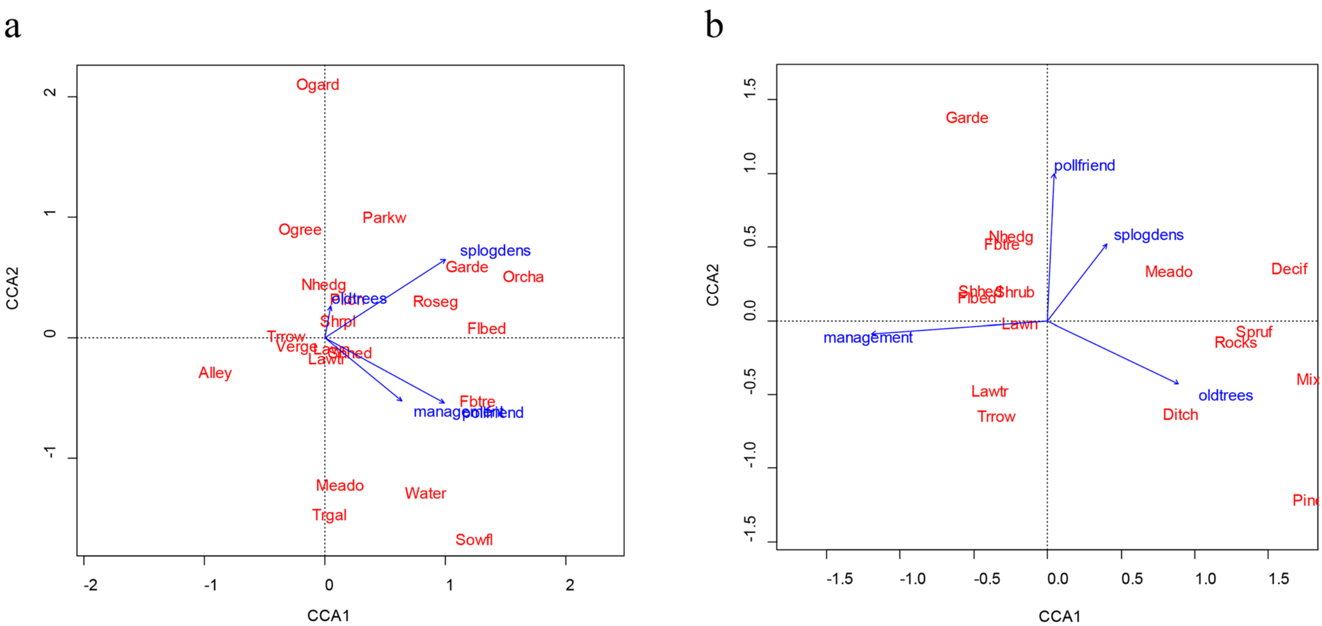

Fig. 7 Canonical correspondence analysis (CCA) (**a**) Lorensborg and Bellevuegården (Malmö); (**b**) Ronna (Södertälje) (Sweden). Red: habitat types: Alley = alley; Decif = deciduous forest; Ditch = ditch; Flbed = flower bed; Fbtre = flower bed with shrubs/trees; Garde = kitchen garden; Lawn = lawn; Lawtr = lawn with trees; Meado = meadow; Mixef = mixed forest; Nhedg = non-sheared hedge; Ogard = ornamental garden; Ogree = green ornamental plantation; Orcha = orchard; Parkw = park wood; Pinef = pine forest; Plion = plantation; Rocks = rocks; Roseg = rose garden; Shhed = sheared hedge; Shrpl = shrub plantation; Sowfl = sown wildflower mixture; Spruf = spruce forest; Trgal = tree gallery; Trrow = tree row; Verge = road verge; Water = water feature. Blue: biodiversity indicators: Floral resources; management = management intensity; oldtrees = abundance of old trees; pollfriend = pollinator friendly; splogdens = species per log area

High management intensity is known to affect biodiversity negatively (e.g. Aronson et al. 2017; Aguilera et al. 2019). However, in our CCA analysis, there was no clear negative association between management intensity and biodiversity.

An additional difference between the areas is their degrees of urbanisation. Lorensborg and Bellevuegården are a part of the city centre in Malmö, without large areas of natural vegetation nearby. Ronna is an urban outpost on the border of rural areas, despite only being located 3 km from the centre of Södertälje. The suburb was built with an ideal of proximity to nature. For example, the rear windows of many high-rise buildings are only a few metres away from forest (Fig. 2d).

Methodological considerations

The chosen methodology for the ecological assessment has to be seen in the context of its applicability in a multidisciplinary context together with public participatory geographic information system (PPGIS) surveys (see Raymond et al. 2021; Stålhammar and Raymond 2024). The approach chosen was therefore comprehensive rather than selective regarding the types of green spaces included in this study. The scale of recording was thus dictated by the degree of detail in the PPGIS survey, and the size of the study area was determined by the size of the two municipalities' planning programmes.

Biodiversity assessment methods are often constrained by resources in terms of time, costs and competences, and the chosen methodology thus has to be adapted according to the resources available. Since the scale and size of the area were given, the methodology had to be adjusted in terms of the type and detail of surveys to be performed. We chose a methodology that can be described as medium intensity regarding inventorying plants. The herbal layer was excluded due to time constraints. The survey of trees and shrubs was not carried out in plots, in circles of a certain radius, or along shorter transects (e.g. Hand et al. 2016; Tzoulas and James 2010; Qiu et al. 2013), but by walking through the whole area. This is more time-consuming than taking samples but gives more comprehensive results. A more selective approach would have been difficult due to the high heterogeneity of woody species, especially in residential areas. A considerable number of recording plots would have been required to capture this.

The indicators we chose are in line with other studies, such as studies of management intensity (Qiu et al. 2013;

Hand et al. 2016) and percentage of native or non-native species (Qiu et al. 2013). Dead wood is less often included in urban biodiversity assessments, but Fröhlich and Ciach (2020) offer a valuable method that should be easy to follow. In the method, in addition to fallen logs and dead standing trees, large dead branches on living trees are also included.

Plenty of flower resources results in high abundance of pollinators (e.g. Gunnarsson and Federsel 2014; Garbuzov and Ratnieks 2014). The inventory of the herbal layer can only partly capture this aspect, since information on flowering is not included (which is often not the case in short cut lawns, for example). When herbal diversity cannot be recorded due to time or other constraints, recording an index for flowering vegetation can be considered as an alternative.

Many studies on biodiversity assessment include indicators for vegetation or habitat structure. These can be canopy cover (e.g. Gonçalves et al. 2021), vegetation cover (e.g. Daniels et al. 2018), vegetation structure (Tzoulas and James 2010), complexity of habitat structure (Qiu et al. 2013) or structural complexity (Hand et al. 2016). There are examples of how to record vegetation structure in urban biodiversity assessments (Hand et al. 2016; vertical structure; Tzoulas and James 2010; Farinha-Marques et al. 2017; vertical structure and cover). However, the relationship between canopy cover and biodiversity (here, tree diversity) does not always seem to be straightforward (Anderson et al. 2021). The importance of bush cover in urban green spaces has been proven to be very relevant for urban animal diversity (Threlfall et al. 2017). In our study, we aimed to include an indicator of vegetation structure, but had to exclude this from the analysis, because it was not sufficiently well defined to be comparable between the two study areas. Regarding habitats and typologies, we intentionally wanted to apply existing classifications. Hermy and Cornelis (2000) can be recommended when a high degree of detail is desired. Still, the classification has to be adapted according to local conditions in pilot studies. The typologies of Cvejić et al. (2015) offered the possibility to classify green spaces at a coarser scale above habitat level. It also included neighbourhood green as a category, which is a key feature in our study areas. Gonçalves et al. (2021) provide a good overview of different types of approaches for biodiversity indicators in the context of biocultural diversity in urban settings.

To assess biodiversity in urban areas, it is often desirable to include animal species. Birds and certain insect groups are most commonly considered (e.g. Hermy and Cornelis 2000; Hand et al. 2016). In this study, animal species were not included due to a lack of time and resources. Recording birds, butterflies and other pollinators in particular could have provided valuable additional information for a biodiversity assessment. There are also examples where citizen science data have been used in urban biodiversity assessments (Li et al. 2019).

The analysis of functional diversity is an aspect that could be included in a biodiversity assessment also in the context of socio-ecological studies (Grilo et al. 2025) or in a planning context (Núñez-Florez et al., 2019). Here we excluded this approach due to time constraints.

In summary, it can be concluded that existing urban biodiversity assessment methods use similar approaches (habitat classification, vascular plant recording, sometimes animal surveys, using various biodiversity indicators mostly for vegetation structure and overall scores to summarise these) to some extent. However, beyond these similarities, every study often uses its own habitat classifications and methods to classify vegetation structure and quality scores, even though suggestions have been made for standardised procedures such as habitat mapping (e.g. Farinha-Marques et al. 2017).

While we applied our methodology in high-rise building areas, it is not only applicable in this type of urban districts. It is applicable for assessment at district level, which means it is too extensive to perform at city level. At a more detailed level (e.g., single parks), other more detailed methods might be more suitable (e.g., Hermy and Cornelis 2000). The method is seen as suitable in particular areas with public green spaces and apartment buildings. However, green spaces in private gardens are not addressed. An advantage of the method is the combination of both direct measures of biodiversity (number of woody species divided by native and non-native) and indicators for biodiversity (e.g. presence of dead wood, flower-rich vegetation). The method gives the possibility to identify and evaluate differences between areas regarding biodiversity at a detailed level and allows identifying deficits.

Applicability to socio-ecological assessment and multifunctional planning

Our assessment method was developed and implemented as part of a socio-ecological assessment of the area. The socio-ecological assessment aims to identify both areas with high ecological and social values and areas that need improvement in terms of either biodiversity aspects or social aspects such as safety, access, and infrastructure for play, sport and other social interactions. In this way, synergies and potential conflicts between ecological and social aspects can also be identified. Examples of synergies include the experience of nature and wildlife in more semi-natural areas. Potential challenges include safety and cleanliness in areas with less intensive management. Both the possibility to experience nature in the neighbourhood and safety issues are especially important aspects in urban areas such as our study areas, with their socio-economic challenges.

According to Hand et al. (2016), there is a lack of '*integrated methods of assessing urban biodiversity that would allow the capture of both social and ecological values of green space and enable better management and planning for urban biodiversity*'. Since then, social-natural system understanding (e.g. Muhar et al. 2018) and socio-ecological studies of urban green spaces (e.g. Daniels et al. 2018; Gonçalves et al. 2021; Kraemer and Kabisch 2021) have increased. Several of these studies present an impressive number of indicators for socio-ecological values. Some of them used fine-scaled spatial data – for example tree inventories – that are not available in our case (Ronna) or only include public green spaces. While biodiversity will be partly captured with these indicators, other important aspects are often left out at the scale on which these studies are performed, for example shrub cover, dead wood, management intensity, etc. At a smaller scale, approaches such as those suggested by Hand et al. (2016) or in this study would be suitable for assessing biodiversity in urban settings in a socio-ecological context.

This study was carried out within a concrete planning context. In both study areas, plan programmes were ongoing. Changes were planned, for example building new housing through densification in Lorensborg and Bellevuegården. In Ronna, densification is included in the long-term strategic planning. Nevertheless, the biodiversity assessment was developed and carried out with the aim of obtaining knowledge about biodiversity and biodiversity indicators, and how biodiversity can be improved. Another aim was to inform planning authorities about the ecological values prevalent in the areas and which aspects needed improvement. However, this study was not carried out to be used as a basis for allocating new buildings. In parallel with this study, the City of Malmö finalised its plan programme for Lorensborg and Bellevuegården. The planned changes imply comprehensive densification with additional buildings, resulting in losses of neighbourhood green and street green in the form of tree avenues, rows of trees and hedges. The planning process in Bellevuegården has been the subject of further scientific analysis (Shahrad 2024; Stålhammar and Raymond 2024). This shows that residential green spaces in Million Housing Programme Areas in Sweden are under pressure from densification processes, which are seen by planners as a sustainable way of achieving compact city planning. The importance of neighbourhood green for inhabitants in Million Housing Programme areas has been emphasised recently (Mack 2021). The way of densifying marginalised housing areas, which have extensive green spaces as a major asset, has been criticised from an environmental justice perspective (Lin et al. 2015; Zalar and Pries 2022). From a biodiversity perspective, the loss of green spaces and especially of trees and shrubs – both in residential areas and in street environments – implies a negative change.

Conclusion

In this study, we developed and applied a method to assess biodiversity in different types of urban green spaces (both in public and residential areas) at city district level. The method uses both direct measures of biodiversity (number of woody species and habitats) and indirect measures (biodiversity indicators as presence of dead wood, water, flower-rich grass vegetation). It allows a grading between areas regarding biodiversity and thus identifies areas with high biodiversity and areas in need for improvements. It is applicable at city district level, in a planning context or together with social-ecological studies.

We applied this methodology in two high-rise building area with low socio-economic status in Sweden in a planning context and within a broader social-ecological study (Raymond et al. 2021). The results revealed a high diversity of shrub and tree species in both areas, where the majority of woody species are non-native. Surprisingly, some residential green spaces reached higher numbers of both habitats and woody species than public parks. Despite a partly rich shrub and tree diversity, in both study areas there is lack of essential ecological features, such as the presence of water, dead wood, flower-rich grass vegetation. This study underlines the importance of residential urban green spaces in this type of city districts. This is especially the case since residential areas in high-rise housing areas with low social economic status are threatened due to densification measures.

Appendix 1

Table 3 Green space typologies according to Cvejić et al. (2015), and their percentage area in the two study areas Lorensborg & Bellevuegården (Malmö) and Ronna (Södertälje), Sweden

		Lorensborg & Bellevuegården		Ronna	
Typology number	Typology name	Number recording units	% area of investigated green spaces	Number recording units	% area of investi-gated green spaces
8	Tree alley and street tree, hedge	28	20%	5	2%
9	Street green and green verge	0	0%	26	12%
14	Large urban park *	7	32%	0	0%
16	Pocket park	2	1%	4	2%
19	Neighbourhood green space	32	38%	126	60%
20	Institutional green space	4	1%	0	0%
22	Green sport facility	1**	0%	0	0%
27	Grassland	0	0%	13	6%
31	Forest	0	0%	35	17%
32	Shrubland	0	0%	2	1%
8 & 16	Street green and pocket park	3	1%	0	0%
8 & 19	Street green and neighbour-hood green	10	6%	0	0%
8 & 20	Street green and institutional green space	5	2%	0	0%
Sum		92	100%	211	100%

* including in this study both large parks and medium size parks, ** dog exercise area

Table 4 Habitat list based on Hermy & Cornelis (2000) with additions/adaptions (in bolt) to the investigated study areas in Malmö and Ronna, Sweden

Habitat types	Frequency in Lorensborg & Bellevuegården (Malmö)	Frequency in Ronna (Södertälje)
1. Planar elements		
1.1. Forest stand: unit composed of a more or less natural forest vegetation		
1.1.1.3. park wood: forest stand of single trees with ligneous undergrowth	6	
1.1.1.4. leafy, regular high forest: forest stand of regular high deciduous trees		18
1.1.2. coniferous wood: forest stand of conifers		
1.1.2.1 pine forest		4
1.1.2.2 spruce forest		2
1.1.3. mixed wood: forest stand of deciduous and coniferous trees		31
1.2. Plantation: unit composed of planted trees	19	
1.2.1. orchard: enclosed unit planted with fruit trees	3	
1.2.3. tree gallery: linear plantation of trees without undergrowth - **but including lawn**	4	
1.4. Shrub plantation: unit composed of shrubs – **including shrub habitats with spontaneous vegetation**	65	70
1.5. Grassland: unit composed of grass species		
1.5.1. lawn: frequently mown grassland	72	119
1.5.1.1 lawn with trees/shrubs	62	88
1.5.3. High grass vegetation	3	74
1.5.6 Sown wildflower-mixture	1	
1.5.7 Outcrops: areas covered by sparsely vegetated rocky areas		25
1.10. Garden: enclosed unit composed of vegetables, fruit or ornamental plants		
1.10.1. kitchen garden: garden composed of vegetables and fruit **(including community gardens)**	5	6
1.10.3. rose garden: garden composed of roses **(including flower beds dominated by roses)**	16	
1.10.4. ornamental garden: garden composed of other ornamental plants	1	
1.11. Ornamental plantation: non-enclosed unit composed of ornamental plants		
1.11.1 Flower bed	8	19
1.11.2 Flower bed with shrubs/trees	16	10
1.11.3 Ornamental plantation –green (ground vegetation not flowering)	3	
1.12. Water feature: unit composed of water	2	
1.14. Car park: unit composed of parking places for vehicles	These were not counted as habitat, but the surrounding hedges or trees (as their according habitat type)	
2. Linear elements		
2.1. Alley: double or four-double row of trees, including the verges	7	
2.2. Tree row: row of trees	47	24
2.3. Hedge: linear wooden vegetation		
2.3.1. sheared hedge: hedge that is regularly sheared	56	40
2.3.2. non-sheared hedge: hedge that is not sheared **(can include trees)**	18	10
2.4. Road verge: non-hardened strip along a road	2	
2.6.1. ditch: watercourse with a width of max. 1 m that may contain water		1

Column 2 and 3 shows frequencies in the two study areas; maximum number of units in Lorensborg & Bellevuegården n=92; in Ronna n=211. Subunits that were not recorded were cut, see Hermy & Cornelis (2000) for the complete list. Units at higher level (in italics) where subunits were recorded were kept

Table 5 Taxa recorded and their frequencies in the two study areas Lorensborg and Bellevuegården (Malmö) and Ronna (Södertälje), Sweden

	Lorensborg & Bellevuegården	Frequency (in % of recording units; n=92)	Ronna	Frequency (in % of recording units; n=211)
Native tree taxa				
Acer campestre	34	37%	*under non-native*	*under non-native*
Acer platanoides	37	40%	120	57%
Alnus glutinosa	0	0%	8	4%
Alnus incana	0	0%	1	0.5%
Aesculus hippocastanum	11	12%	*under non-native*	*under non-native*
Betula pendula	18	20%	104	49%
Betula pubescens	1	1%	5	2%
Carpinus betulus	11	12%	*under non-native*	*under non-native*
Fagus sylvatica	18	20%	*under non-native*	*under non-native*
Fraxinus excelsior	13	14%	12	6%
Picea abies	0	0%	45	21%
Pinus sylvestris	1	1%	74	35%
Populus tremula	0	0%	68	32%
Prunus avium	27	29%	63	30%
Prunus padus	19	21%	15	7%
Quercus robur	6	7%	40	19%
Salix alba	6	7%	*under non-native*	*under non-native*
Salix caprea	0	0%	30	14%
Salix spp.	4	4%	34	16%
Sorbus aucuparia	21	23%	94	45%
Sorbus intermedia	9	10%	49	23%
Tilia cordata	3	3%	23	11%
Tilia spp.	10	11%	0	0%
Ulmus glabra	51	55%	25	12%
Sum taxa	**19**		**18**	
Native shrub taxa				
Cornus sanguinea	20	22%	7	3%
Corylus avellana	15	16%	28	13%
Cotoneaster scandinavicus	0	0%	10	5%
Crataegus spp.	46	50%	33	16%
Cytisus scoparius	1	1%	0	0%
Frangula alnus	0	0%	3	1%
Ilex aquifolium	1	1%	0	0%
Juniperus communis	1	1%	14	7%
Lonicera xylosteum	1	1%	7	3%
Prunus spinosa	16	17%	14	7%
Ribes alpinum	12	13%	0	0%
Ribes nigrum/rubrum	8	9%	7	3%
Rubus sp.	9	10%	7	3%
Rubus idaeus	*under cultivar*	*under cultivar*	28	13%
Sambucus nigra	45	49%	23	11%
Sambucus racemosa	0	0%	1	0.5%
Taxus baccata	11	12%	*under non-native*	*under non-native*
Viburnum opulus	0	0%	15	7%
Sum taxa	**13**		**14**	
Non-native tree species or cultivars				
Acer spp.	9	10%	0	0%
Acer campestre	*under native*	*under native*	5	2%
Acer palmatum	0	0%	1	0.5%
Acer pseudoplatanus	27	29%	2	1%
Acer saccharinum	0	0%	1	0.5%
Acer tataricum ssp ginnala	0	0%	12	6%

Table 5 (continued)

	Lorensborg & Bellevuegården	Frequency (in % of recording units; n=92)	Ronna	Frequency (in % of recording units; n=211)
Aesculus hippocastanum	*under native*	*under native*	12	6%
Betula spp.	2	2%	0	0%
Carpinus betulus	*under native*	*under native*	1	0.5%
Celtis occidentalis	1	1%	0	0%
Cercidiphyllum japonicum	3	3%	0	0%
Corylus colurna	1	1%	0	0%
Fagus sylvatica	*under native*	*under native*	3	1%
Ficus carica	3	3%	0	0%
Ginko biloba	1	1%	0	0%
Gleditsia triacanthos	2	2%	0	0%
Juglans regia	12	13%	0	0%
Larix decidua	0	0%	3	1%
Magnolia spp.	2	2%	0	0%
Malus domestica	6	7%	29	14%
Malus spp.	26	28%	0	0%
Mespilus germanica	1	1%	0	0%
Metasequoia glyptostroboides	1	1%	0	0%
Morus spp.	1	1%	0	0%
Picea spp.	0	0%	1	0.5%
Pinus spp.	7	8%	4	2%
Platanus spp.	15	16%	0	0%
Populus spp.	12	13%	8	4%
Prunus domestica	3	3%	1	0.5%
Prunus maackii	0	0%	4	2%
Prunus serrulata Kanzan	4	4%	0	0%
Prunus spp.	14	15%	0	0%
Pyrus communis	1	1%	0	0%
Pyrus salicifolia	2	2%	0	0%
Pyrus spp.	2	2%	0	0%
Quercus spp.	6	7%	0	0%
Robinia spp.	14	15%	0	0%
Salix spp.	20	22%	0	0%
Salix alba	*under native*	*under native*	2	1%
Sorbus spp.	9	10%	0	0%
Sorbus incana	0	0%	2	1%
Styphnolobium japonicum	1	1%	0	0%
Tilia tomentosa	2	2%	0	0%
Tilia x europaea	18	20%	0	0%
Ulmus minor hoersholmii	1	1%	0	0%
Zelkova serrata	2	2%	0	0%
Sum taxa	**34**		**17**	
Non-native shrub species or cultivars				
Amelanchier spp.	28	30%	6	3%
Aronia melanocarpa	0	0%	2	1%
Berberis spp.	12	13%	24	11%
Buddleja spp.	19	21%	0	0%
Buxus sempervirens	5	5%	5	2%
Caragana arborescens	2	2%	1	0.5%
Chaenomeles spp.	1	1%	0	0%
Clematis spp.	0	0%	1	0.5%
Clematis vitalba	34	37%	0	0%
Cornus spp.	21	23%	0	0%
Cotinus spp.	4	4%	0	0%

Table 5 (continued)

	Lorensborg & Bellevuegården	Frequency (in % of recording units; n=92)	Ronna	Frequency (in % of recording units; n=211)
Cotoneaster spp.	60	65%	30	14%
Crataegus spp.	8	9%	0	0%
Dasiphora spp.	30	33%	13	6%
Deuzia spp.	6	7%	0	0%
Euonymus spp.	21	23%	1	0.5%
Fallopia japonica	0	0%	2	1%
Forsythia spp.	27	29%	0	0%
Fuchsia spp.	1	1%	0	0%
Hibiskus spp.	7	8%	0	0%
Humulus lupulus	0	0%	2	1%
Hydrangea spp.	8	9%	8	4%
Hypericum spp.	3	3%	0	0%
Hypericum inodorum	0	0%	4	2%
Juniperus spp.	0	0%	5	2%
Juniperus squamata	1	1%	0	0%
Kerria spp.	6	7%	0	0%
Laburnum anagyroides	3	3%	4	2%
Ligustrum spp.	22	24%	10	5%
Lonicera caerulea	0	0%	1	0.5%
Lonicera tatarica	39	42%	1	0.5%
Lycium chinense	0	0%	1	0.5%
Mahonia spp.	24	26%	1	0.5%
Malus toringo	6	7%	0	0%
Nerium oleander	1	1%	0	0%
Paeonia spp.	0	0%	6	3%
Parthenocissus spp.	0	0%	2	1%
Philadelphus spp.	30	33%	9	4%
Prunus laurocerasus	27	29%	9	4%
Pyracantha spp.	22	24%	0	0%
Rhododendron spp.	4	4%	23	11%
Rhus typhina	3	3%	0	0%
Ribes aureum	2	2%	0	0%
Ribes sanguineum	8	9%	0	0%
Ribes uva-crispa	2	2%	0	0%
Rosa spp	63	68%	100	47%
Rubus idaeus (cult)	2	2%	*see above*	*see above*
Rubus rubus (cult)	1	1%	*see above*	*see above*
Salix repens (cult)	2	2%	0	0%
Sambucus nigra (cult black lace)	1	1%	0	0%
Sorbaria spp.	10	11%	0	0%
Sorbaria sorbifolia	0	0%	7	3%
Sorbus spp.	6	7%	0	0%
Spirea spp.	52	57%	38	18%
Stephanandra spp.	5	5%	4	2%
Staphylea pinnata	1	1%	0	0%
Symphoricarpus spp.	40	43%	20	9%
Syringa spp.	35	38%	0	0%
Syringa meyeri	0	0%	2	1%
Syringa vulgaris	0	0%	31	15%
Taxus spp.	*under native*	*under native*	7	3%
Thuja spp. /*Chamaecyparis* spp.	7	8%	29	14%
Viburnum spp.	30	33%	3	1%
Vitis vinifera	0	0%	2	1%

Table 5 (continued)

	Lorensborg & Bellevuegården	Frequency (in % of recording units; n=92)	Ronna	Frequency (in % of recording units; n=211)
Weigela spp.	13	14%	5	2%
Wisteria spp.	2	2%	0	0%
Sum taxa	**51**		**37**	

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Data availability No datasets were generated or analysed during the current study.

Declarations

Competing interests The authors declare no competing interests.

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